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HOLOGRAPHY AND ITS PRACTICAL EMPLOYMENT, (U)

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FOREIGN TECHNOLOGY DIVISION

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by

L. D. Bakhrakh, S. B. Gurevich
G. A. Gavrilov

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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю*	Yu, yu
П п	*П п*	P, p	Я я		Ya, ya

*<u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ë in Russian, transliterate as yë or ë. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α α α	Nu	Ν ν
Beta	Β β	Xi	Ξ ξ
Gamma	Γ γ	Omicron	Ο ο
Delta	Δ δ	Pi	Π π
Epsilon	Ε ε ϵ	Rho	Ρ ρ ϱ
Zeta	Ζ ζ	Sigma	Σ σ ς
Eta	Η η	Tau	Τ τ
Theta	Θ θ ϑ	Upsilon	Υ υ
Iota	Ι ι	Phi	Φ φ ϕ
Kappa	Κ ϰ κ ϰ	Chi	Χ χ
Lambda	Λ λ	Psi	Ψ ψ
Mu	Μ μ	Omega	Ω ω

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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HOLOGRAPHY AND ITS PRACTICAL EMPLOYMENT

Corresponding Member of the AS USSR [Academy of Sciences USSR] L. D. Bakhrakh, Doctor of Physico-Mathematical Sciences S. B. Gurevich, Candidate of Physico-Mathematical Sciences G. A. Gavrilov

Holography is an all-purpose method for recording and reproducing wave fields with the purpose of revealing the necessary information both on an object which is a radiation source and on the nature of the wave field.

The idea of a holographic method for recording and restoring images was first proposed in 1948 by the English scientist D. Gabor who, in 1971, was awarded the Nobel Prize for Physics for this

discovery. In the Soviet Union the first work on holography was done by Yu. N. Denisyuk from 1958 to 1962.

The development of the holographic method was aided by the work of N. G. Basov, A. M. Prokhorov, and Ch. Tauns, which led to the creation of a powerful coherent radiation source - the laser. This discovery permitted the American scientists E. Lieth and Yu. Upatniyeks [as transliterated] in 1962 to obtain the first laser holograms of diffusely reflecting objects.

In recent years interest in holography has sharply grown all over the world. This is explained by the fact that it opens possibilities for solving problems which cannot be solved by any other methods, or that it permits obtaining the necessary results more simply and effectively than by other ways.

The practical uses of holography are so varied that to examine all of them in one article is impossible. Therefore we will dwell on several of the more urgent uses where the most typical properties of the holographic method are used.

As is known, with the aid of holography we can reproduce truly three-dimensional images of objects, and also three-dimensional represemtions of phenomena and processes which occur in a specific

volume. Of course, it is most natural to use this property in image technology, television, and the cinema.

The work of Yu. N. Denisyuk to a significant degree aided the accomplishment of the possibility for using holography in image technology. The method which he proposed for recording holograms in three-dimensional media simplifies the process of restoring images from such holograms, since the images can be obtained in white light. These holograms can be used for training-demonstration purposes, in the advertising business, in the construction of artistic panoramas, in the designing of exhibitions, etc.

The use of holography in television is associated with substantial difficulties; first of all in connection with the necessity to coordinate the tremendous volume of information which is contained in the hologram with the throughput capacity of television systems; also, secondly, because of the absence at the present time of receiving and transmitting devices which are suitable for holographic television. If a broadcasting holographic television system is a matter of the comparatively distant future, then holographic systems of closed-circuit television can be created in the near future. These systems are indispensable in all cases where a three-dimensional orientation is needed, for example, in work with manipulators in nuclear industry or with the docking of spaceships.

The creation of three-dimensional cinema is also connected with overcoming substantial difficulties - obtaining large-size holograms, their projections without distortions, with the holographing of full-scale scenes, etc. Holographic movie systems in which an image is observed by a small number of spectators, for example in aircraft trainers and in instrument landing systems of aircraft, can be realized comparatively simply. In the latter case the pilot sees alternating three-dimensional images of the landing strip which are restored from the holograms and sequentially shown on command from a computer. The computer works together with a radar station and accomplishes a change in holograms in accordance with the position of the aircraft in space.

The ability of holograms to reproduce three-dimensional images is also used in various fields of science and technology. Here it permits conducting a posteriori processing of the results for the entire volume studied from one single hologram, which is especially important with the investigation of rapidly-proceeding processes and phenomena. This processing of the results of investigations provides the possibility to gain both in the time for conducting an experiment and in the resources which are required for this. For example, under conditions of a labor-intensive and expensive experiment on

aeroballistic routes from a single hologram made in one experiment we can obtain, using all of the known methods of visualization of phase objects (Fig. 1), any number of photos which detect details in various points of the object.

The processing of holographic images is widely used for analyzing particles which move in a specific volume (holographic disdrometry - Fig. 2). We can "freeze" the particles and then sequentially analyze the image in its various cross-sections. Thus, a check of turbulent liquid jets is accomplished, aerosols are studied, the processes in the internal volumes of stream-driven turbines and the internal combustion chambers of engines are observed, and the growth and breakdown of vapor drops are investigated.

The holographic method permits simplifying the equipment for recording tracks in bubble chambers and, in certain cases, increasing resolution. The experiments for recording tracks (Fig. 3) showed the possibility for increasing the "charge" of chambers (recorded events)and, consequently, the effectiveness of accelerators.

The property of a hologram to reproduce three-dimensional images of an object which is positioned in the field of action of acoustic oscillations opens prospects for creating ultraphonoscopic systems. The specifics of acoustic holography consist of the use of

comparatively large wavelengths and, as a result, linear detectors. This permits discontinuing the introduction of a reference beam in the plane of the receiving antenna and introducing it by an electronic method. Since the restoration of acoustic holograms is accomplished by visible light, the visualization of acoustic images is thereby conducted; however, here the problem of minimizing distortions caused by the great difference in waves of ultrasound and light arises.

Acoustic holography is promising for solving problems connected with ultrasonic flaw detection, for investigating the structure of the earth's crust, and for searching for mineral resources. No less important is its employment in oceanography and sonar detection.

There is particular interest in acoustic holography for medicine. Ultrasound is more sensitive to a change in the characteristics of specific tissues than X-ray beams, and with moderate intensity is harmless. Therefore, we can look forward to using holography for three-dimensional viewing of anatomical structures of bone and soft tissues, for observing the internal organs of living objects, and for recording pathological changes. Unfortunately, the majority of work in this field of acoustic holography has not yet left the confines of laboratory investigations.

In the range of comparatively long waves which are used in radio and acoustic holography, a method of synthesized aperture can be realized which substantially increases the resolution of systems. It first acquired development in radar. The essence of the method consists of the space-time processing of signals which are received. A hologram is formed sequentially according to the mutual motion of the object being studied and the receiving antenna. If the antenna is installed on an airplane, then the resolution in the restored image will be determined not by its physical dimensions, but by the length of the route traversed by the aircraft, i.e., by the dimensions of the radiohologram (Fig. 4). For resolution on the terrain, radar systems with a synthesizd aperture are comparable with systems of aerial photography and, at the same time, have significant advantages over them: all-weather capability, obtaining images at a great distance from the carrier.

The synthesized aperture method can be used for mapping the earth's surface, for glacial and geophysical surveillance, and in agriculture. Its use for space research, for example obtaining radar maps of planets with optically impervious atmosphere (Venus), is extremely promising. Synthesizing an aperture can be accomplished because of the movement of planets. It is precisely in this manner

that an experiment was accomplished, as a result of which a radio image of the moon's surface was obtained: the transmitter and receiver were positioned on the earth, and synthesizing was accomplished because of the movement of the moon (Fig. 5).

Holograms very often find employment as a means of transforming wave fronts. Specifically, holograms are used as optical elements: a lens, a grating, and correctors. The focusing properties of zonal plates which are a hologram of a point source and a flat reference wave are well known. On one photographic plate a multitude of holograms (up to 1000) of point sources can be recorded. These holograms possess an unusual ability to simultaneously reproduce a large number of identical images and can be used, for example, in the technology of producing microcircuits, in optical systems for multichannel information processing, etc.

Holograms can also be used as noncontact templates in the technology of microelectronics (these templates insure resolution on the order of 1 μm on a surface of up to 50 mm, they do not suffer from the impact of particles, and do not wear down), and for producing diffraction gratings. These gratings are simple to obtain, and have large size and high diffraction efficiency - up to 90 o/o.

The transformation of wave fronts with the aid of holograms

opens a unique possibility to obtain quality images despite the distorting action of nonuniform and scattering media. For recording the images under these conditions two properties of a hologram are important. First of all, in the case of the passing of reference and object waves of one or another nonuniformity, the hologram proves to be undistorted; secondly, the passing of a wave sequentially through a medium and a hologram of the given medium gives an undistorted wave front.

The use of holography for transforming wave fronts is promising, for example, for eliminating the effect of nonuniformity of the atmosphere on an image of space objects, and for compensating aberrations of optical elements and systems.

Holography can be used in interferometric investigations. Here it permits accomplishing interference of wave fronts which exist at various moments in time, and also studying objects with complex form as much as is desired. The greatest popularity was obtained by the method of double exposure and interferometry in real time. In the first case, two different states of one or another object, the images of which interfere during restoration, are recorded on a hologram; in the second - the observation of an object in various states is conducted through a hologram in the presence of a restoring beam.

Holographic interferometry is used, specifically, for investigating vibrations (Fig. 6 gives interferograms of vibrating turbine blades). This has great practical value for nondestructive quality control of parts. Nondestructive quality control of articles in industry is based on the widely distributed holographic methods of investigating deformations. So, in the United States a device was developed for checking the internal defects of automobile tires which detects any internal defects: bubbles, flaking, etc. (Fig. 7). Holographic interferometry permitted a substantial expansion of the study of phased objects. It is being successfully employed in aerodynamic investigations and in plasma physics (Fig. 8).

The ability to record a great amount of information in conjunction with the possibility of its more rapid read-out permits us to successfully use holography for creating memory devices for various functions. The advantages of holographic memory devices are high density of the recording (up to 10^8-10^9 bit/cm^2), low sensitivity to microdefects of the carrier and to contamination in the place of recording (the recording corresponds to each element of the stored information not in a specific point of the hologram, but in its entire area), the absence of intermediate optics (which substantially simplifies the structure of the system and its adjustment), low requirements for accuracy of the placement of a transparent beam on a hologram (since even a part of the hologram

restores the entire image), the absence of scanning devices, convenience of operations with samples (because all of the restored images from a matrix of the holograms are formed in one and the same place), and the potential possibility for accomplishing a recording of information in a three-dimensional medium. In this case the density of the recording can reach 10^{12}-10^{13} bit/cm^3. These devices will find use first of all in computer technology. There is a basis to assume that they will be widely used for creating fixed and immediate-access storage of computers.

The advantages of the holographic method for storing information can be successfully realized for recording television and movie programs on a special film with the subsequent reproduction of an image on screens of normal television receivers. This system, apparently, will be simpler and cheaper than other systems of video recordings which are intended for mass consumption.

Holographic methods in conjunction with methods of coherent optics open wide possibilities for supplementing the means for optical processing of information.

The ability of holograms to transform optical fields and record simultaneously their amplitudes and phases permits the creation of different instruments, specifically analog devices for detecting or

differentiating images (automatic reading of printed text, detecting the desired images on the terrain photos - aerial photo reconnaissance, aerial photo inspection, aerial photo geologic prospecting, etc., automatic dactyloscopic search - identification of complete fingerprints, etc.).

A more complex problem is the recognition of images. Here each of the possible classes of images (forms) is described not by one previously-known realization, but by a multitude of random [realizations]. The basis of recognition devices is a multichannel optical correlator which uses two-dimensional holographic screens. The scope of the problems which are solved by these recognition devices is extremely wide: the identification of various objects according to their image, the recognition of manuscript text, the automatic analysis of aerial photographs with the purpose of detecting objects of desired classes, the recognition of chromosomes and other microbiological objects, the dactyloscopic analysis of incomplete and distorted fingerprints in criminology, etc.

Experiments showed that holography can be successfully used with the recognition of different kinds of signals, preliminarily transformed into images, for example with the recognition of voice or hydroacoustic and radar signals.

We should note two possible uses of holography in automatic control systems with optical ties for stabilizing objects by means of tracking their image or for navigational tie-in of aircraft by using visual reference points (the image of terrain, stars, the image of parts of the surface of planets, etc.), which is of exceptional interest for purposes of space navigation. The solution to these problems is connected with the use of matched holographic filters. Calculations show that such filters insure an extremely high accuracy of stabilization or tie-in which is practically unattainable by other means. The process of tracking an image is reduced to tracking a bright spot on the output of the filter which corresonds to the maximum of a function of automatic correlation of the input image. Such devices are now in the stage of experimental investigations.

Presently the work in the field of holography and optical methods of processing information has attained a level on which the question of introducing the results into practice arises with all urgency. The basic difficulties in the path of realizing the possibilities of the holographic method are connected with the element and instrument base of holography. Fundamentally new devices and instruments are needed for input and output of information, as are modulators and deflectors of light, holographic devices, and their elements. We need to create a wide assortment of highly-sensitive materials for recording holograms which permit the

accomplishment of repeated recirculation of information and expanding the assortment of lasers which are designed for use in holographic devices.

For coordinating work in the field of holography and optical methods of processing information, the Scientific Council on Holography was organized with the Department of General Physics and Astronomy of the Academy of Sciences USSR which contains four sections: optical holography, radio and acoustic holography, optical methods of processing information, and recording media and means of holography equipment. The Council composed a plan and programs for investigations in the field of holography for different periods. The successful accomplishment of these investigations will, to a significant degree, depend on the joint efforts of the institutions which are heading the work on holography, and will make a substantial contribution to scientific and technical progress.

Fig. 1. Aerodynamic investigations with the aid of holography on ballistic trajectories: 1 - Schlieren photograph, 2 - blade from behind, 3 - blade from in front, 4 - blade from below, 5 - defocused filament; 6 - interferogram of displacement, 7, 8 - interferograms from two holograms.

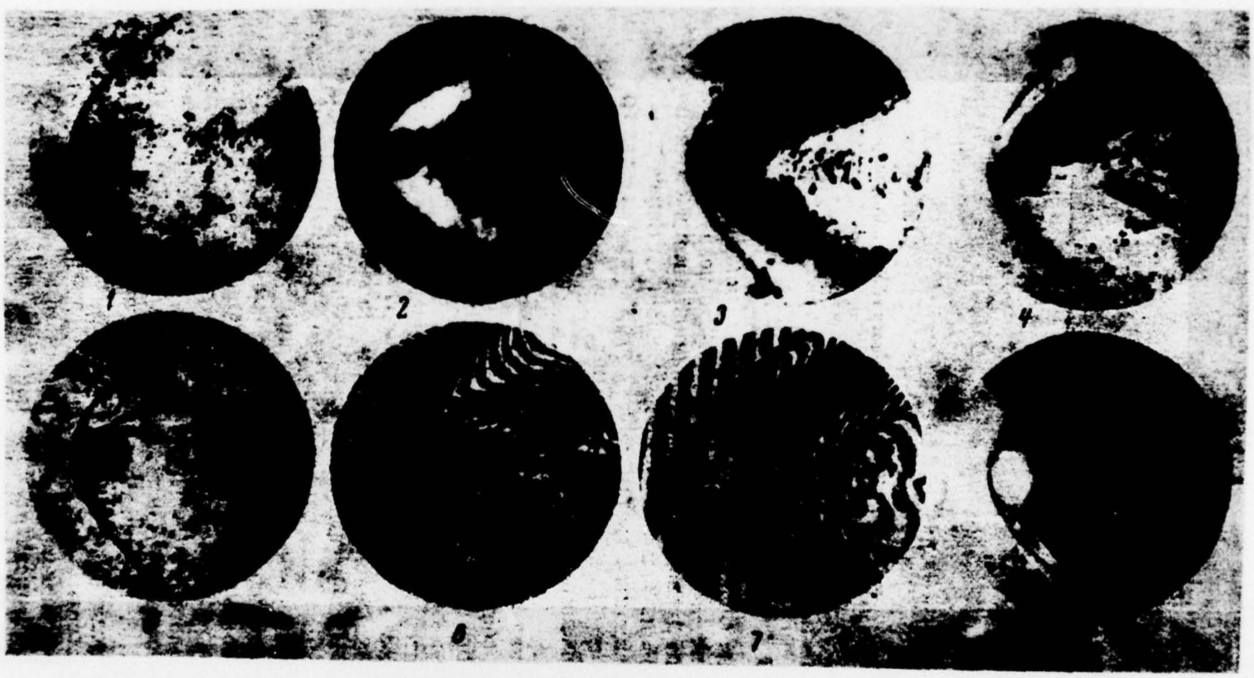


Fig. 2. Holographic disdrometry: 1 - a jet of liquid spray from a swirl nozzle, 2 - image of floating bubbles in liquid.

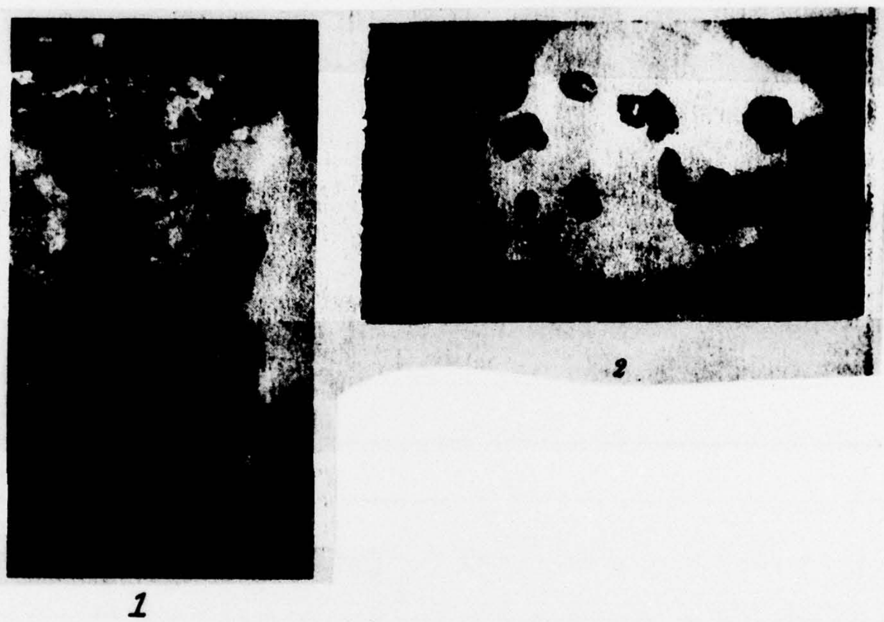


Fig. 3. Restored images from a hologram (Г) of a freon bubble chamber with a volume of 0.7 liters. M - a dull scatterer, 1, 5 - reference wires and their restored images, 2, 3, 4, 4' - the planes of restoration and their corresponding true images of tracks of electron-positron pairs, formed with the conversion of γ-quanta, $E_\gamma = 100$ MeV.

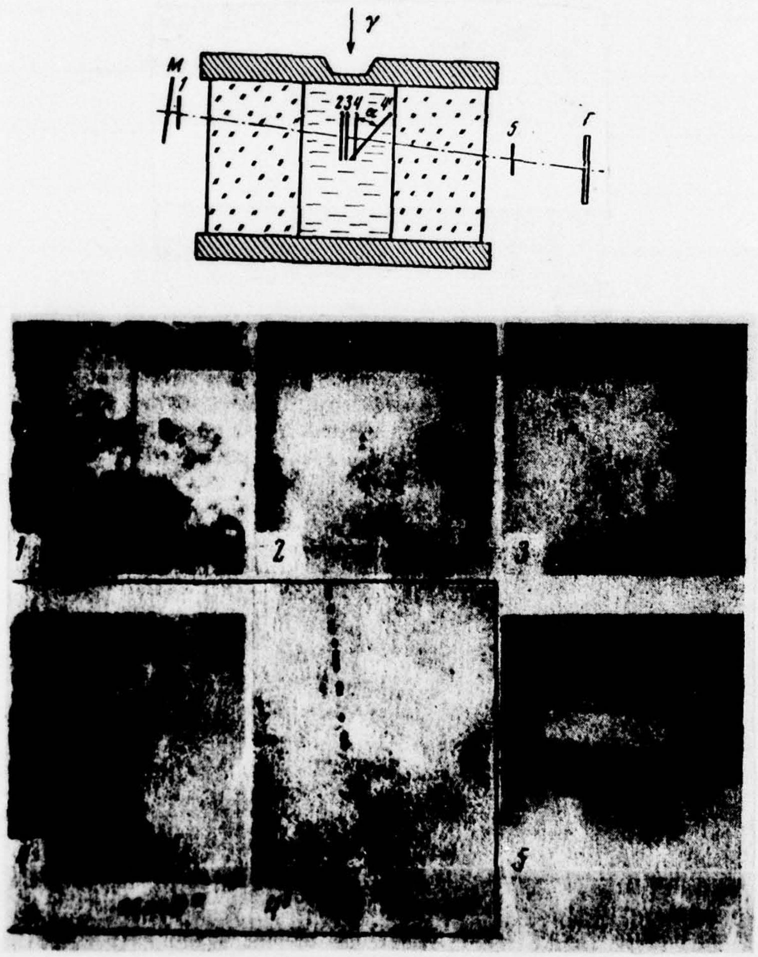


Fig. 4. Radar with synthesized aperture: 1 - principle of operation of the locator, 2 - optical recording of signals from the terrain in the locator, 3 - restored image of the terrain.

Key: (1) Length of synthesis, (2) scanning zone.

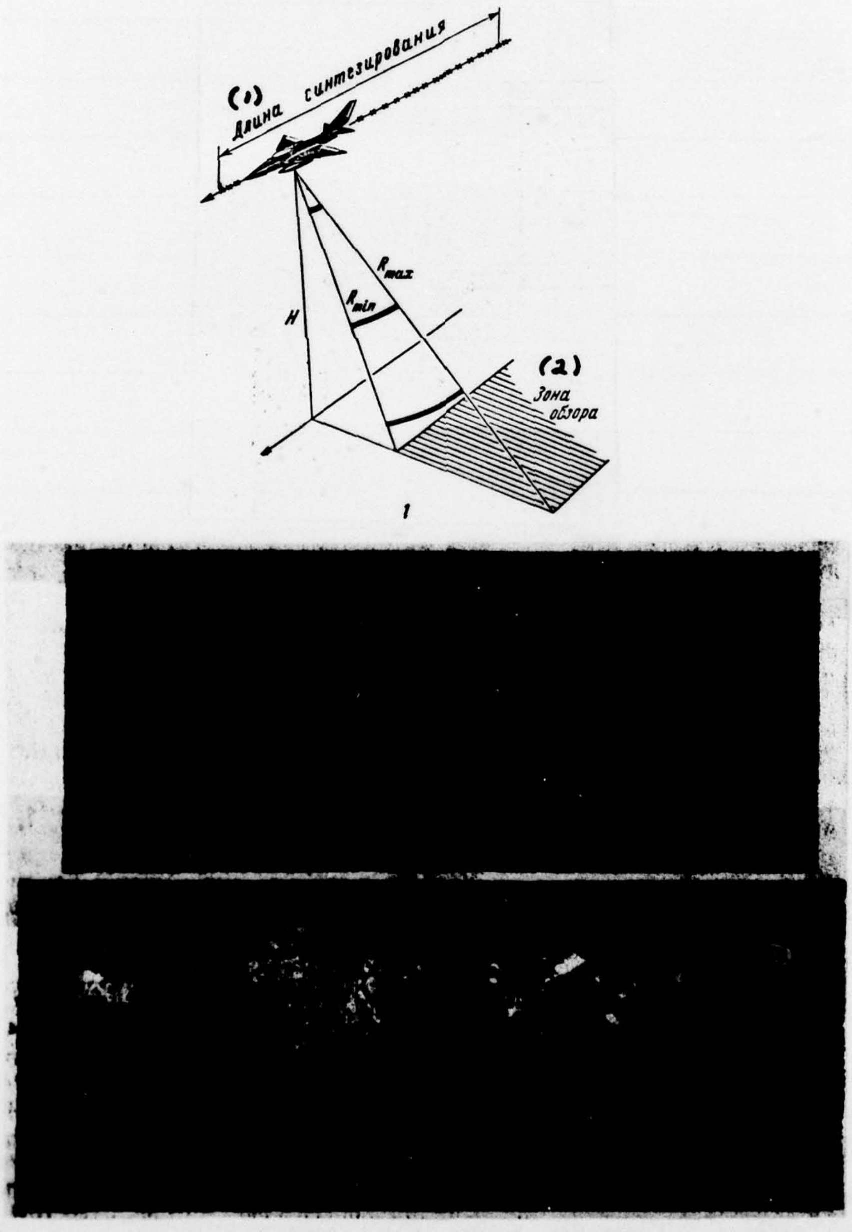
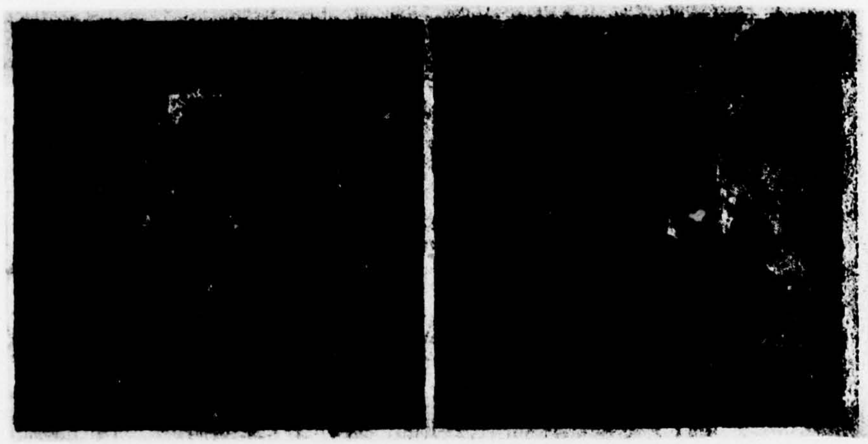


Fig. 5. Image of the lunar surface. 1 - radio image, 2 - optical image.

Fig. 6. Investigation of the vibrations of turbine blades.

Key: (1) Hz.



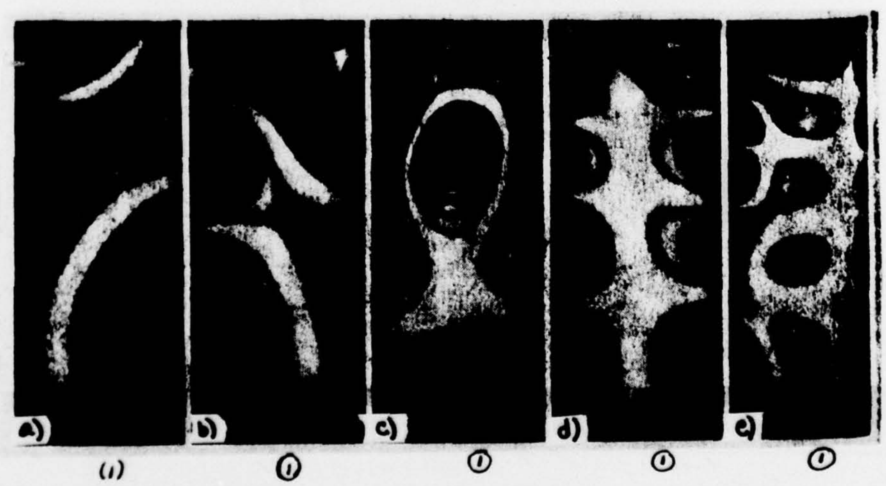
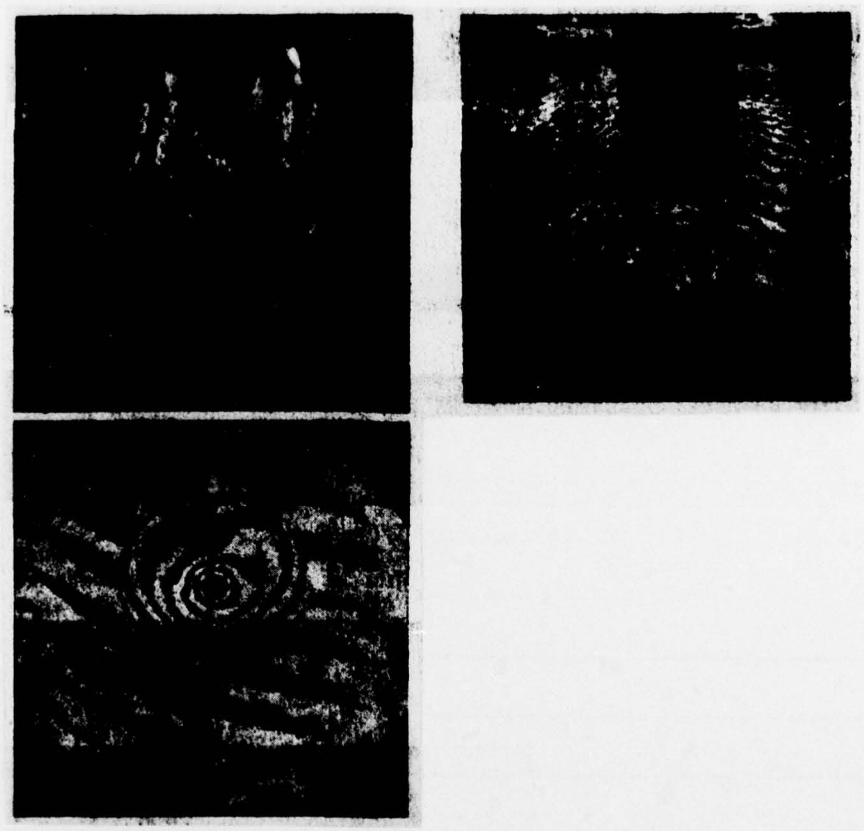


Fig. 7. Interferogram of an automobile tire (the arrows show defects which have been detected).

Fig. 8. Holographic interferometry: 1 - interferogram of a pulsed arc charge of a laser pumping tube in the cathode region, 2 - interferogram of a shock wave and plasma formed with electrical explosion of wire, 3 - interferogram of the growth process of a crystal from an aqueous solution.



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